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BOREHOLE PLUGGING PROGRAM (WASTE DISPOSAL)

Report 1

INITIAL INVESTIGATIONS AND PRELIMINARY DATA

by

John A. Boa, Jr.

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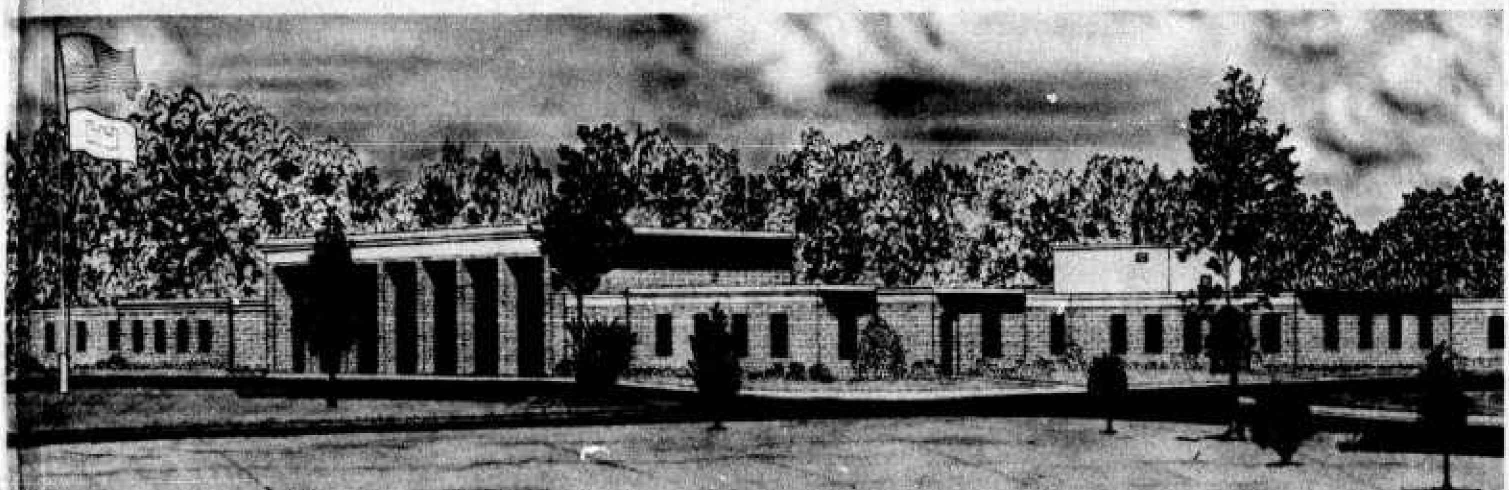

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This report covers efforts during the first year of the program. A study was initiated to find competent grouts to be used in stemming boreholes associated with radioactive waste disposal. The grouts must be durable for several thousand years and be essentially impermeable. In addition, the grouts should be pumpable to depths of several thousand feet into environments of high temperature. Grouts for use in both salt and nonsalt formations are to be studied. This program is still underway.

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PREFACE

This report of the first year's effort was prepared to assist Sandia Corp. personnel in preparing an Environmental Reports and Site Characterization Report in support of a Waste Isolation Pilot Plant (WIPP). The aforementioned reports will be prepared beginning 6 January 1978.

The work was conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under the direction of Messrs. B. Mather, John M. Scanlon, R. A. Bendinelli, and J. A. Boa, Jr. Mr. Boa is the author of this report.

Commander and Director of the WES during the period of study was COL John L. Cannon. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
square feet	0.09290304	square metres
cubic feet	0.02831685	cubic metres
gallons (U. S. liquid)	3.785412	cubic decimetres
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	0.006894757	megapascals
pounds (mass) per cubic foot	16.0185	kilograms per cubic metre
pounds (mass) per cubic yard	0.5933	kilograms per cubic metre
ounces (U. S. fluid) per cubic foot	1.04437923	cubic decimetres (litres)
pounds (mass) per gallon	119.8264	kilograms per cubic metre
feet per second	0.3048	metres per second
Fahrenheit degrees	5/9	Celsius degrees or

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

BOREHOLE PLUGGING PROGRAM (WASTE DISPOSAL)

INITIAL INVESTIGATIONS AND PRELIMINARY DATA

PART I: INTRODUCTION

Background

1. Discussions were begun in July 1975 and are continuing between Mr. C. W. Gulick of Sandia Corporation (SC) and members of the staff of the U. S. Army Engineer Waterways Experiment Station (WES) Concrete Laboratory, Grouting Branch, concerning the development of pumpable, durable cement-based, expansive grouts for possible use in stemming boreholes which exist in areas where radioactive waste will be disposed. These grouts are not intended for use in the holes which actually contain the waste.

2. Cement grouts were considered to be advantageous because of ease of placement and economical materials costs. Based on current technology, they are believed to be capable of being developed to have physical and chemical properties compatible with the various earth strata through which the boreholes were drilled. In addition, cement-based grouts could be expected to be of adequate durability. Conventional, existing equipment, such as that used in petroleum production, developed for batching, mixing, and placing grouts was to be used and the mixtures were to be proportioned accordingly.

3. Subsequent detailed discussions centered around the development of grouts containing a particular cement that has previously been found to be resistant to sulfate attack. Grout development was to produce mixtures having resistance to groundwater attack, low permeability to both water and gas, and controlled expansive characteristics along with the normal properties of hardened and unhardened grouts such as flow, workability with time, time of setting, and unconfined compressive strength. Additionally, tests for changes in bond strength, compressional wave velocity, dynamic modulus of elasticity, and porosity as a function of time were to be conducted on specimens subjected to varying environments.

4. It was suggested by Mr. Gulick that the initial mixture proportions consist of both a highly expansive cement and a shrinkage-compensating expansive cement, a fly ash, and a natural pozzolan. It was later decided to also include one or more high-range water reducers. It was felt that the addition of both fly ash and a natural pozzolan to the grout mixtures might result in a denser hardened mixture, i.e. one with less void space than mixtures containing neither fly ash nor a natural pozzolan. This reduction in void space could conceivably result in a grout mixture of lower permeability than that previously attainable in what might be called a more normal grout (i.e. a grout containing only cement and water). In addition, longer pumping time could be achieved and a decrease in cost could be expected by the addition of fly ash and a natural pozzolan.

5. An attempt was to be made to develop an accelerated test method that could be used to subject grout samples to the environmental effects of several thousand years.

6. Grouts were to be developed for emplacement in both salt and nonsalt formations.

Objectives

7. The major objective of this program was to develop one or more mixtures that can be pumped into boreholes, have a working time of 2 to 3 hours, and be of long-term durability. Also, the mixtures should have permeabilities not over a few microdarcies and should not be subject to attack by local groundwater.

Scope

8. The investigation reported herein involved materials selection, proportioning studies, and specimen testing using not only the constituents previously mentioned but also a Type III (high early strength) portland cement, retarders, fresh and salt waters as the mixing water, and several pozzolans.

PART II: MATERIALS AND PROCEDURES

Grout Materials and Mixture Proportioning

9. Several hundred mixtures were proportioned; 59 were studied in some detail, and 5 were selected for further testing. The mixture proportions of the 59 are shown in Table 1. The five mixtures selected for further study are also shown in Table 1 (and also in Tables 2 and 9).

10. The grout mixture materials investigated thus far and the source of each are listed below.

Material	Source
ChemComp cement	Southwestern Portland Cement Co.
ChemStress cement	Southwestern Portland Cement Co.
Portland cement, Type III	Southwestern Portland Cement Co.
Fly ash	Halliburton Co.
Filter-Cel*	Johns-Manville Products Corp.
Basalite*	Basalt Rock Co., Inc.
Tufa*	Monolith Portland Cement Co.
Frianite*	California Industrial Minerals Co.
Salt (TFC Purex)	Morton Salt Co.
Salt (Kleer)	Morton Salt Co.
Dolomite sand (-12)	Calumet and Hecla Corp.
Limestone sand (-16)	Vulcan Materials Co.
Melment L-10	American Admixtures Co.
Plastiment	Sika Chemical Corp.
Nopco NXZ	Diamond Shamrock Chemical Co.
Bentonite	Halliburton Co.

* Natural pozzolans: Filter-Cel is uncalcined diatomite, Basalite is calcined shale, Tufa is uncalcined tuff, and Frianite is pumicite.

Testing Program and Procedures

11. The five mixtures selected for further study were tested for dynamic modulus of elasticity, compressional wave velocity, unconfined compressive strength, bond strength (pushout), unrestrained volume change, porosity, flow (workability with time), time of setting, and permeability.

12. Generally, the procedures used to determine each of these

properties were in accordance with the procedures in Handbook for Concrete and Cement.* The test number and title for each procedure are listed below. Special procedures are described below also.

Dynamic modulus of elasticity: CRD-C 18-59, Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequency of Concrete Specimens.

Compressional wave velocity: CRD-C 51-72, Standard Method of Test for Pulse Velocity Through Concrete.

Unconfined compressive strength: CRD-C 14-73, Compressive Strength of Cylindrical Concrete Specimens. (The specimens used in the tests reported herein were 3- by 6-in.** cylinders.)

Flow: CRD-C 79-58, Method of Test for Flow of Grout Mixtures.

Time of setting: An automatic time of setting apparatus was used for these results. The concept is similar to that described in CRD-C 82-76, Method of Test for Time of Setting of Grout Mixtures.

Bond strength: A special test was devised whereby a section of steel pipe, 6 in. in diameter, in a vertical position was filled, and sections were cut off at specified ages. The grout was pushed from the steel pipe and its bond strength was calculated.

Unrestrained expansion: 3- by 3- by 10-in. prisms were cast and demolded at varying ages and length change measurements were made.

Porosity: 2-1/8-in.-diam specimens were cored from cast grout specimens, and the porosity was determined by subjecting these specimens to 1200-psi water pressure and calculating the porosity from an increase in weight. Specimens were dried initially to constant weight prior to testing.

Permeability: CRD-C 98-73, Method of Test for Water Permeability of Concrete. This test consists of subjecting specially prepared specimens to 200-psi water pressure for a period of days and computing the permeability from the inflow rate. A deviation from the standard test method was utilized in that instead of tap water, a special water was prepared simulating groundwater chemistry from analysis supplied by SC. This water was used in the permeability tests and to inundate selected specimens. The formula for the simulated groundwater is shown in Table 8.

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* U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, Aug 1949 (with quarterly supplements), Vicksburg, Miss.

** A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

PART III: TEST RESULTS AND DISCUSSION

13. Tables 2-9 show results of tests and present a discussion of the results where applicable; the five mixtures selected for further study are identified in Table 2. Tables 3-8 are limited to results of these five mixtures.

14. In addition to these results, the pH level of the simulated groundwater in which selected specimens were stored showed an increase from the initial value range of 6.3 to 7.0 to a maximum of 11.2 at 2-1/2 months age. This is noteworthy because it indicates that all the acid has been consumed and that the water is not now as harmful as it was initially. This is not applicable where groundwater is moving and is constantly in contact with the grout, thus bringing in a new supply of acid.

15. Consideration was given to the vacuum treatment of a grout column. A brief description of a small-scale laboratory test and recommendations follow.

16. The effects derived from the application of a vacuum to the surface of freshly placed concrete are documented in the literature. The effects of a vacuum on freshly placed grout should be analogous (i.e. a reduction in the water-to-cement ratio and a corresponding densification and increase in compressive strength). Increased densification and compressive strength are, to some degree, indicators of decreased porosity and permeability, both of which are desired properties of borehole plugs.

17. To test these assumptions a laboratory vacuum pump was connected to a wellpoint 36 in. in length and 2 in. in diameter. The wellpoint was positioned in the center of an 8-in.-diam pipe segment containing a freshly mixed pumpable grout. A vacuum of 24 to 26 in. was applied for varying times. Water was removed from the grout mixture in all instances. Subsequent density and unconfined compressive strength tests on cores from the hardened grout revealed an increase in density and compressive strength compared with control specimens cast from the same mixture, but not vacuumed.

18. Further study would be needed to determine if these laboratory techniques can be adapted to the scale of actual field borehole plugging operations, and if so, then the feasibility (i.e. benefits derived from vacuuming) would need to be proved by a systematic laboratory test program comparing vacuumed with nonvacuumed grout.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

19. Tests have been under way since August 1976. Considerable data have been generated and are being evaluated. Generally speaking, it is too early to form any definite conclusions on the program results as a whole; however, some interim conclusions can be drawn from some of the data available.

20. Some refinements might be made in mixture proportions to yield more workable mixtures for field usage, especially from the standpoint of maintenance of workability for sufficient time (up to 3 hr) to allow for placement. In addition, the time of setting needs to be reduced for mixture BPN-FA-BS-SP-P-1.

21. That the four mixtures containing the special cements and large amounts of pozzolan were effectively impermeable under the specified test conditions is very promising when one considers the fact that the one mixture containing normal portland cement had measureable permeability (Table 7).

22. No conclusions can be drawn as yet from the dynamic modulus and compressional wave velocity data (Table 3) because the variation between ages is too small and within the range of error of the testing equipment.

23. The partial results of the volume-change measurements (Table 5) indicate positive expansion in a wet environment and could lead to the conclusion of bond strengths in excess of those shown in Table 4 with no accompanying decrease with time.

24. Porosity results are somewhat misleading when looked at by themselves, because the results show that the mixture with the lowest porosity also was the only mixture which had observable permeability. One possible explanation would be that the mixture with the observable permeability was the only one which did not contain one or both expansive cements.

25. It is recommended that all tests currently under way be continued to the tentative one-year completion date, then analyzed as to results and trends with a discussion at that time whether to continue

testing the same specimens or casting specimens of new mixtures. There will be a limited number of specimens remaining at the end of the one-year tests which could be used for further testing.

26. Additional conclusions are included as footnotes to the various tables herein.

PART V: RESEARCH PLANNED FOR THE FUTURE

27. A considerable number of areas should be investigated in the future. These areas are described below.

- a. Continue efforts in the area of mixture proportioning to incorporate as much cement and selected pozzolan as possible into a variety of mixtures commensurate with workability and pumpability, maintaining the lowest possible water/cement ratio.
- b. Research the possibilities of achieving an accelerated test to determine the long-term effects of groundwater, pressure, and elevated temperature on hardened grouts.
- c. Conduct gas-permeability tests on mixtures now being studied, coupled with water-permeability tests at a higher pressure level than currently used.
- d. Study effects of groundwater under pressure on unhardened and semihardened grouts simulating actual downhole conditions of temperature and pressure. This would be a real-time experiment.
- e. Study specimens physically cast under pressure. These specimens should be cast in a variety of different types of molds with external pressure, to simulate approximately 500 lin ft of grout, applied in order to simulate more closely downhole pressure conditions. In addition, specimens would be subjected to elevated temperatures beginning the instant they are cast and continuing throughout a testing program. These specimens would be tested for volume change and permeability. This would also be a real-time experiment with the possibility of using these specimens in the accelerated test mentioned above.
- f. Enlarge the methods used to determine volume change by casting prototype diameter plugs of nominal length, possibly pressurized, subjected to programmed elevated temperatures, and appropriately instrumented. This type of casting has been done in the past with the exception of the varied, controlled temperature and pressure.
- g. Study the densification of grouts under pressure.
- h. Investigate possible use of chemical matching grout.
- i. Continue testing of field samples from boreholes plugged in New Mexico. Specimens will be tested for permeability and porosity.
- j. Investigate possible use of API Class H cement due to

its reported low water demand. This cement could possibly be combined with pozzolans and a high-range water reducer to produce an especially dense, highly impermeable mixture.

k. Investigate the possible combination of Class H cement with ChemComp and ChemStress cements.

l. Run X-ray diffraction patterns on specimens cast at elevated temperatures and pressure to determine expansive components formed as compared with those formed when specimens are not subjected to elevated temperatures and pressures. In addition, run X-ray patterns on specimens currently under test for comparative purposes.

m. Determine porosities both before and after permeability tests on specimens that are permeable.

n. Examine all grouts currently under test with the scanning electron microscope (specimens to be examined at the same age). Freeze older specimens until younger specimens reach age of older frozen specimens. By this method, a direct visual comparison can be made. Photograph specimens.

o. Determine porosities after permeability tests run on the same specimens that were physically tested for permeability.

p. For permeable specimens, rerun permeability tests at a later age (probably one year) to determine if there is a decrease in permeability possibly brought on by the specimen being saturated with the simulated groundwater for this extended period of time.

q. Experiment with the possibility of substituting a powdered water-reducing admixture for the liquid water-reducing admixture currently being utilized. A powdered admixture would be easier to incorporate into the mixtures for field placement and, in fact, a powdered admixture will be mandatory in the event continuous mixing, as opposed to batch mixing, is used. As a means to this end examine both Halliburton's CFR-2 and Dowell's D-65.

r. Include restrained volume change measurements using 3- by 3- by 10-in. prisms in conjunction with the unrestrained expansion measurements now being used (Table 5).

s. Make an analysis of the hardened specimens of the five grouts under study to determine what the organic content is, if any.

t. Information obtained in March 1977 indicates that the new New Mexico site now under study has a groundwater analysis different from the one used in preparing the simulated groundwater used to date in the permeability studies and other tests requiring inundation. It has been suggested and generally agreed upon that the simulated groundwater currently being utilized represents one of the worst conditions that could be encountered in the field. Suggestions have been made to increase the potassium ion content by weight to approximately 50,000 parts per million to more closely simulate groundwater from the new area. In addition, it will be necessary to obtain a groundwater analysis from the new area for other possible changes. It has also been suggested that an analysis be made for silica (SiO_2) that might possibly have been leached from the permeability specimens. This was suggested because the analysis showed that potassium (K) was present in the simulated groundwater even though none had been used in the preparation of the water (Table 8).

u. Make computer finite element analysis on a related expansive cement program and compare the results with those of the borehole plugging program as a guide for future work.

v. Use a strain gaged, thin-wall conduit (6 to 10 in. by approximately 10 ft long) in a vertical position with a pressure gage at the bottom of the conduit; fill with grout and note the pressure decay with time as the grout stiffens and correlate this with strain gage movement.

w. Place a fluorescent dye in the simulated groundwater used in the permeability determinations and then dissect specimens to determine from observation under ultraviolet illumination the permeability path and degree of saturation.

x. Investigate the bonding properties of selected grout mixtures to various types of rock, e.g. dolomites, anhydrites, halites, sandstones, etc.

y. Study the revised representative brine solutions for Waste Isolation Pilot Plant (WIIP) experimentation (Table 10). This information was supplied by SC in June 1977.

z. Initiate a study of the need and effect of salt in a mixed grout to possibly improve bonding and decrease dissolution of the borehole surface. This study and the one suggested in subparagraph y can be performed concurrently.

aa. Make continued readings on the specimens currently under test for as long as the specimens exist (i.e. Table 6). Nondestructive testing could conceivably continue for quite a long while (e.g., Tables 3 and 5); however, no bond strength specimens (Table 4) will be available after one year.

bb. Accumulate data from a variety of tests now under way in connection with the field grouting of ERDA-10, Carlsbad, New Mexico. Furnish this information to SC. In addition, furnish SC with one-year data upcoming soon on three of the five mixtures selected as mentioned earlier.

cc. Formulate plans for testing not previously performed including: (1) preparing and using the new water formulation (Table 10) in future permeability determinations and inundation of specimens; (2) gas permeability tests on specimens that exhibited low or no permeability; (3) tests on specimens subjected to pressures and temperatures that would normally be found in a borehole several thousand feet in depth; (4) water permeability tests on specimens previously run and companion specimens not previously run which are at least one year old.

Table 1

Grout Mixture Proportions

Material	Unit of Measure	Mixture Designation and Batch, BP-519-								
		8	12	16	8M	12M	16M	8MP	12MP	16MF
ChemComp cement	lb/ft^3	33.00	30.00	27.00	42.81	40.02	36.13	45.52	43.06	39.23
ChemStress cement		9.00	9.00	9.00	11.67	12.00	12.04	9.00	9.00	9.00
Fly ash		9.92	9.22	8.50	12.87	12.30	11.37	12.87	12.30	11.37
Filter-Cel (pozzolan)		2.20	3.06	3.77	2.85	4.09	5.05	2.85	4.09	5.05
Melment L-10 (water reducer)		--	--	--	2.18	2.08	1.93	2.18	2.08	1.93
Plastiment (retarder)	oz/ft^3	--	--	--	--	--	--	2.32	2.22	2.05
Water	lb/ft^3	43.67	44.50	45.40	38.14	38.55	39.69	38.14	38.55	39.69
Density	lb/ft^3	97.8	95.8	93.7	108.3	107.0	104.3	108.4	107.0	104.3
	lb/gal	13.1	12.8	12.5	14.5	14.3	13.9	14.5	14.3	13.9
Cement factor										
All cements	lb/yd^3	1134	1053	972	1471	1405	1301	1472	1405	1302
Cements + fly ash	lb/yd^3	1402	1302	1202	1818	1737	1608	1820	1738	1609
Water/cement ratio, by weight										
All cements	--	1.04	1.14	1.26	0.70	0.74	0.82	0.70	0.74	0.82
Cements + fly ash	--	0.84	0.92	1.02	0.57	0.60	0.67	0.57	0.69	0.67

(Continued)

Note: BPN-FA-SP-P and BPN-FA-BS-SP-P-1 specimens cast 16 Aug 1976.
BP-521-25MP and BPN-CS-FA-1 specimens cast 15 Dec 1976.
BPN-FA-BS-SP-P-1 (Type III) specimens cast 22 Feb 1977.

Table 1 (Continued)

Material	Unit of Measure	Mixture Designation and Batch, BP-520-								
		20	30	40	20M	30M	40M	20MP	30MP	40MP
ChemComp cement	lb/ft^3	40.00	36.50	33.00	48.98	44.00	39.60	51.06	45.85	41.40
ChemStress cement		9.00	9.00	9.00	11.02	10.85	10.80	9.00	9.00	9.00
Fly ash		11.57	10.75	9.92	14.17	12.96	11.90	14.17	12.96	11.90
Basalite sand (pozzolan)		6.95	9.69	11.94	8.51	11.68	14.33	8.51	11.68	14.33
Melment L-10 (water reducer)		--	--	--	1.21	1.19	0.88	1.21	1.19	0.88
Plastiment (retarder)	oz/ft^3	--	--	--	--	--	--	2.56	2.33	2.14
Water	lb/ft^3	38.69	38.90	39.35	33.38	34.10	34.76	33.38	34.10	34.76
Density	lb/ft^3	106.2	104.8	103.2	116.1	113.6	111.4	116.1	113.6	111.4
	lb/gal	14.2	14.0	13.8	15.5	15.2	14.9	15.5	15.2	14.9
Cement factor										
All cements	lb/yd^3	1323	1229	1134	1620	1481	1361	1622	1481	1361
cement + fly ash	lb/yd^3	1635	1519	1402	2003	1831	1682	2004	1831	1682
Water/cement ratio, by weight										
All cements	--	0.79	0.85	0.94	0.56	0.62	0.69	0.56	0.62	0.69
Cements + fly ash	--	0.64	0.69	0.76	0.45	0.50	0.56	0.45	0.50	0.56

(Continued)

Table 1 (Continued)

Material	Unit of Measure	Mixture Designation and Batch, BP-521-								
		25	35	45	25M	35M	45M	25MP*	35MP	45MP
ChemComp cement	lb/ft3	35.00	30.00	25.00	41.76	36.01	30.24	43.54	37.85	32.17
ChemStress cement		9.00	9.00	9.00	10.74	10.80	10.89	9.00	9.00	9.00
Fly ash		10.39	9.22	8.04	12.40	11.07	9.72	12.40	11.07	9.72
Tufa (pozzolan)		8.25	10.22	11.47	9.84	12.27	13.87	9.84	12.27	13.87
Melment L-10 (water reducer)		--	--	--	2.10	1.87	1.64	2.10	1.87	1.64
Plastiment (retarder)	oz/ft3	--	--	--	--	--	--	2.76	2.46	1.75
Water	lb/ft3	40.38	41.62	43.16	36.14	37.47	39.15	36.14	37.47	39.15
Density	lb/ft3	103.0	100.1	96.7	110.9	107.6	103.9	110.9	107.7	103.9
	lb/gal	13.8	13.4	12.9	14.8	14.4	13.9	14.8	14.4	13.9
Cement factor										
All cements	lb/yd3	1188	1053	918	1418	1264	1111	1419	1265	1112
Cements + fly ash	lb/yd3	1469	1302	1135	1752	1563	1373	1753	1564	1374
Water/cement ratio, by weight										
All cements	--	0.92	1.07	1.27	0.69	0.80	0.95	0.69	0.80	0.95
Cements + fly ash	--	0.74	0.86	1.03	0.56	0.65	0.77	0.56	0.65	0.77

(Continued)

* Mixture selected for further testing.

Table 1 (Continued)

Material	Unit of Measure	Mixture Designation and Batch, BP-522-								
		25	35	45	25M	35M	45M	25MP	35MP	45MP
ChemComp cement	lb/ft^3	35.00	30.00	25.00	43.35	37.52	31.56	45.52	39.79	33.94
ChemStress cement		9.00	9.00	9.00	11.15	11.26	11.36	9.00	9.00	9.00
Fly ash		10.39	9.22	8.04	12.87	11.53	10.15	12.87	11.53	10.15
Frianite (pozzolan)		8.21	10.18	11.42	10.17	12.73	14.42	10.17	12.73	14.42
Melment L-10 (water reducer)		--	--	--	2.18	1.95	1.72	2.18	1.95	1.72
Plastiment (retarder)	oz/ft^3	--	--	--	--	--	--	2.32	2.30	1.83
Water	lb/ft^3	40.38	41.62	43.16	35.15	36.43	38.14	35.15	36.43	38.14
Density	lb/ft^3	103.0	100.0	96.6	112.7	109.5	105.6	112.7	109.5	105.7
	lb/gal	13.8	13.4	12.9	15.1	14.6	14.1	15.1	14.6	14.1
Cement factor										
All cements	lb/yd^3	1188	1053	918	1472	1317	1159	1473	1318	1160
Cements + fly ash	lb/yd^3	1469	1302	1135	1819	1628	1433	1820	1629	1433
Water/cement ratio, by weight										
All cements	--	0.92	1.07	1.27	0.65	0.75	0.89	0.65	0.75	0.89
Cement + fly ash	--	0.74	0.86	0.83	0.52	0.60	0.72	0.52	0.60	0.72

(Continued)

Table 1 (Continued)

Material	Unit of Measure	BPN	BPNSP	BPNSP-R	BPN-BS	BPN-BS-SS**	BPN-BS-SS-SP-P**	BPN-BS-SS-SP-P-1**	BPN-BS-SS-SP-P-1(A)**
		Mixture Designation and Batch							
ChemComp cement	lb/ft^3	57.00	72.20	74.62	51.35	20.00	30.50	35.84	35.84
ChemStress cement		9.00	11.40	9.00	8.11	9.00	10.98	9.27	9.27
Natural salt (Morton TFC Purex)		--	--	--	13.34	7.94	7.27	7.69	7.69
Natural salt (Morton Kleer)		--	--	--	--	58.82	54.90	49.44	49.44
Melment L-10 (water reducer)		--	1.67	1.67	--	--	1.66	1.80	1.80
Plastiment (retarder)	oz/ft^3	--	--	3.56	--	--	1.77	1.92	2.88
Water	lb/ft^3	41.11	35.46	35.46	37.03	22.06	20.18	21.36	21.36
Density	lb/ft^3	109.2	119.1	119.1	109.8	117.8	123.8	123.6	123.6
	lb/gal	14.6	15.9	15.9	14.7	15.7	16.6	16.5	16.5
Cement factor, all cements	lb/yd^3	1782	2257	2258	1605	783	1120	1218	1218
Water/cement ratio, by weight, all cements	--	0.62	0.42	0.42	0.62	0.76	0.49	0.47	0.47

(Continued)

** Mixtures contain salt as fine aggregate. The salt aggregate is shown as Morton Kleer and is not dissolved in mixture water. It is in the mixture as sand would be in a similar mixture.

Table 1 (Continued)

Material	Unit of Measure	Mixture Designation and Batch				
		BPN-FA-BS-SP-P-1*	BPN-FA-BS-SP-P-2	BPN-FA-BS-SP-P-3	BPN-FA-BS-SP-P-4	BPN-FA-BS-SP-P-1 (Type III)*
ChemComp cement	lb/ft^3	55.21	47.97	62.26	69.08	--
Portland cement, Type III		--	--	--	--	55.21
Fly ash		18.58	25.12	12.22	6.04	18.58
Natural salt (Morton TF Purex)		11.43	11.32	11.53	11.63	11.43
Melment L-10 (water reducer)		1.48	1.46	1.49	1.50	1.48
Plastiment (retarder)	oz/ft^3	2.94	1.53	1.99	2.21	2.94
Water	lb/ft^3	31.73	31.43	32.03	32.30	31.73
Density	lb/ft^3	116.9	115.8	118.0	119.1	116.9
	lb/gal	15.6	15.5	15.8	15.9	15.6
Cement factor						
All cements	lb/yd^3	1491	1295	1681	1865	1491
Cement + fly ash	lb/yd^3	1992	1973	2011	2028	1992
Water/cement ratio, by weight						
All cements	--	0.57	0.66	0.51	0.47	0.57
Cements + fly ash	--	0.43	0.43	0.43	0.43	0.43

(Continued)

* Mixture selected for further testing.

Table 1 (Continued)

Material	Unit of Measure	Mixture Designation and Batch				
		BP-DS	BP-DS-SP-P	BP-LS	BP-LS-SP-P	BP-LS-SP-P-3
ChemComp cement	lb/ft^3	30.00	36.00	30.00	49.08	48.61
ChemStress cement		9.00	9.00	9.00	9.00	--
Bentonite		0.90	0.90	0.90	2.50	--
Dolomite sand (-12)		50.00	66.65	--	--	--
Limestone sand		--	--	60.00	45.00	60.76
Melment L-10 (water reducer)		--	1.80	--	1.70	0.73
Plastiment (retarder)	oz/ft^3	--	1.91	--	3.71	2.07
Water	lb/ft^3	31.79	24.00	27.25	26.00	24.3
Density	lb/ft^3	121.7	136.6	127.2	131.6	133.7
	lb/gal	16.3	18.3	17.0	17.6	17.9
Cement factor	lb/yd^3	1053	1215	1053	1568	1312
Water/cement ratio, by weight, all cements	--	0.82	0.53	0.70	0.45	0.5

(Continued)

Table 1 (Concluded)

Material	Unit of Measure	Mixture Designation and Batch				
		BPN-FA-SP-P*	BPN-FA-BS-SS-SP-P**	BPN-FA-BS-SS-SP-P-1**	BPN-CS-FA-1*	BPN-CS-FA-2
ChemComp cement	lb/ft^3	61.12	39.78	39.78	62.02	60.43
ChemStress cement		--	--	--	9.00	9.00
Fly ash		20.56	13.40	13.40	16.76	16.38
Natural salt (Morton TFC Purex)		--	8.43	8.43	--	--
Natural salt (Morton Kleer)		--	36.27	36.27	--	--
Melment L-10 (water reducer)		1.63	2.13	2.13	1.72	1.39
Plastiment (retarder)	oz/ft^3	2.60	2.54	2.54	3.02	2.95
Nopco NXZ (air detraining agent)	lb/ft^3	--	--	0.08	--	--
Water	lb/ft^3	34.31	23.39	23.39	32.66	33.33
Density	lb/ft^3	116.0	121.3	121.3	120.4	119.1
	lb/gal	15.5	16.2	16.2	16.1	15.9
Cement Factor						
All cements	lb/yd^3	1650	1074	1074	1864	1875
Cement + fly ash	lb/yd^3	2205	1436	1436	2370	2317
Water/cement ratio, by weight						
All cements	--	0.56	0.59	0.59	0.46	0.48
Cements + fly ash	--	0.42	0.44	0.44	0.37	0.39

* Mixture selected for further testing.

** Mixture contains salt as fine aggregate. The salt aggregate is shown as Morton Kleer and is not dissolved in mixture water. It is in the mixture as sand would be in a similar mixture.

Table 2

Freshly Mixed and Hardened Data

Mixture Designation	Unconfined Compressive Strength* 28 Days Age psi	Time of Setting hr		Flow, sec			
		Initial	Final	+5 min	+1 hr	+2 hr	+3 hr
BP-519-8	1750	--	--	10.0	11.0	12.0	12.5
BP-519-12	1600	--	--	10.0	11.0	12.0	13.0
BP-519-16	1550	7-1/2	15	10.5	12.0	13.0	13.5
BP-519-8M	4620	--	--	19.0	17.6	21.0	33.0
BP-519-12M	3960	--	--	27.0	23.0	46.0	None
BP-519-16M	3490	4-3/4	7	23.0	25.0	37.0	None
BP-519-8MP	4790	--	--	17.0	15.0	17.0	19.0
BP-519-12MP	4780	--	--	30.0	20.0	22.0	25.0
BP-519-16MP	4030	--	--	36.0	27.0	27.0	31.0
BP-520-20	1500	--	--	14.8	12.6	12.8	13.2
BP-520-30	1460	--	--	13.0	12.0	11.8	11.2
BP-520-40	1320	6-3/4	14-1/4	10.4	10.2	10.2	10.2
BP-520-20M	4950	--	--	16.0	22.2	40.0	None
BP-520-30M	4640	--	--	12.0	14.2	17.0	None
BP-520-40M	3450	4-3/4	11	11.0	12.0	13.0	16.0
BP-520-20MP	5910	--	--	14.0	17.2	21.0	25.0
BP-520-30MP	5130	--	--	11.7	12.4	13.2	14.2
BP-520-40MP	4630	8-1/2	11	10.2	11.2	11.2	11.8
BP-521-25	3710	--	--	11.0	15.0	15.5	21.0
BP-521-35	2380	--	--	10.0	11.0	12.0	13.1
BP-521-45	2000	8	13	9.2	10.0	10.0	10.0
BP-521-25M	5620	--	--	14.0	19.0	None	None
BP-521-35M	4740	--	--	13.3	15.0	27.0	None
BP-521-45M	4465	--	--	10.8	11.5	17.0	22.6
BP-521-25MP**	5940	--	--	12.8	13.2	15.0	16.4
BP-521-35MP	4790	--	--	11.2	11.2	12.8	13.4
BP-521-45MP	3350	6-1/4	8-1/2	10.0	11.2	12.0	14.4
BP-522-25	2220	--	--	10.2	13.0	13.9	16.6
BP-522-35	1615	--	--	9.8	11.0	11.4	11.6
BP-522-45	1130	--	--	9.2	10.0	10.2	10.6
BP-522-25M	5230	--	--	17.3	18.0	21.2	29.2
BP-522-35M	4190	--	--	14.0	16.0	16.0	31.0
BP-522-45M	3230	--	--	11.0	15.7	14.2	16.7

(Continued)

Note: Flow was determined at 65°-70°F. Test method consisted of time of efflux of 1725-ml grout through a 1/2-in. orifice from a cone-shaped container. Note, particularly, that in some instances the flow actually decreased with time. This is unusual and attributed to the water reducer used. Flow was determined on mixture mixed for 3 min. every 15 min.

Time of setting <u>Final</u> set was that time when specimen had hardened. <u>Initial</u> set was determined to be the time when a 1-mm needle ceased to pass a point 5 mm from the base of a test specimen.

Unconfined compressive strength was determined on 3- by 6-in. cylinders cut from a 3- by 20-in. cylinder and cured, sealed, at ~65° to 70°F. Strengths shown are at 28 days age; however, strengths will also be determined at 1-yr age and the specimens containing pozzolans can be expected to increase in strength, some more drastically than others.

* If the unconfined compressive strength was below 3000 psi the mixture was not considered for further testing.

** Five mixtures selected for further testing.

Table 2 (Concluded)

Mixture Designation	Unconfined Compressive Strength 28 Days Age psi	Time of Setting hr Initial	Final	Flow, sec +5 min	+1 hr	+2 hr	+3 hr
BP-522-25MP	5030	--	--	17.5	20.0	24.0	39.2
BP-522-35MP	5160	--	--	13.5	14.0	14.0	15.0
BP-522-45MP	4100	--	--	11.6	12.0	12.5	12.7
BPN	3470	--	--	10.5	13.2	16.0	18.0
BPNSP	6625	--	--	16.0	54.0	None	None
BPNSP-R	8840	6-1/4	8-1/4	12.0	16.5	21.6	31.5
BPN-BS	2140	--	--	9.6	10.8	11.0	11.0
BPN-BS-SS	1800	--	--	14.2	20.6	21.2	21.3
BPN-BS-SS-SP-P	5270	3-1/4	7-1/4	19.2	20.2	None	None
BPN-BS-SS-SP-P-1	5380	--	7	17.0	22.0	30.0	None
BPN-BS-SS-SP-P-1(A)	5420	--	--	15.5	19.4	28.0	40.0
BP-DS	2520	--	--	12.2	15.8	17.0	21.2
BP-DS-SP-P	7360	--	--	21.0	22.0	None	None
BP-LS	3540	3-1/4	6	13.0	18.0	None	None
BP-LS-SP-P	7710	10-1/4	12	15.0	20.0	26.0	32.0
BP-LS-SP-P-3	7570	--	--	13.5	18.0	27.0	None
BPN-FA-BS-SP-P-1**	5380	28†	31	13.2	21.0	24.2	28.6
BPN-FA-BS-SP-P-2	4380	20	23	18.0	29.0	29.0	24.6
BPN-FA-BS-SP-P-3	5380			14.4	32.2	40.0	23.0
BPN-FA-BS-SP-P-4	6050			13.0	27.0	38.0	26.0
BPN-FA-BS-SP-P-1 (Type III)**	5060	~20††	~23	~15.0††	~25.0	~30.0	None
BPN-FA-SP-P**	7570	5-3/4	12-1/2	15.2	20.0	21.0	23.4
BPN-FA-BS-SS-SP-P	5090	--	55	15.0	19.2	24.0	27.0
BPN-FA-BS-SS-SP-P-1‡	4810						
BPN-CS-FA-1**	8980	7	11-3/4	18.0	22.0	25.6	None
BPN-CS-FA-2	7920	8	14	16.6	31.6	38.6	None

** Five mixtures selected for further testing.
† These times can be decreased by decreasing retarder amount to obtain a more realistic setting time for field use.
†† Estimated.
‡ Same mixture as BPN-FA-BS-SS-SP-P except an air-detraining agent was added.

Table 3

Dynamic Modulus and Compressional Wave Velocity

Test	Specimen Age	Specimen Condition	Mixture: BNP-FA-SP-P	BPN-FA-BS-SP-P-1	BPN-CS-FA-1	BP-521-25MP	BPN-FA-BS-SP-P-1 (Type III)
Dynamic modulus, psi × 10^6	28-day		2.36	1.94	3.39	2.30	2.10
	56-day	Wet	2.91	2.09	3.35	2.37	2.30
		Dry			3.20	2.30	2.20
	90-day	Wet	2.79	2.02	3.43	2.34	2.25
		Dry	2.32	1.83	3.31	2.44	2.05
	180-day	Wet	2.83	2.00	3.36	2.33	2.29
		Dry	2.00	1.95	3.32	2.40	2.12
	1-year	Wet	2.74	2.17	(Dec 77)		(Feb 78)
		Dry	2.48	2.21			
Compressional wave velocity ft/sec	28-day		11,465	10,430	12,860	11,300	10,860
	56-day	Wet	11,220	10,360	12,440	10,875	11,220
		Dry			12,345	10,970	11,245
	90-day	Wet	12,085	10,700	12,500	11,155	10,590
		Dry	11,855	10,570	12,675	11,405	11,190
	180-day	Wet	11,590	10,340	13,435	11,730	10,225
		Dry	11,110	10,430	13,305	11,615	10,350
	1-year	Wet	11,825	10,825	(Dec 77)		(Feb 78)
		Dry	11,365	10,635			

Note: Specimens were cured 0-28 days at 120°F.
Results shown as "wet" indicate specimens were stored in specially prepared water to simulate groundwater from a site near Carlsbad, NM.

The 28-day results are on specimens prior to inundation. All results listed as wet were of specimens continuously inundated from 28-day-age on.

These were nondestructive tests to determine whether the simulated groundwater, in the case of the wet specimens, had a detrimental, lasting effect on the hardened specimens. Thus far, no significant changes are evident.

Table 4

Bond Strength

Mixture	Results, psi, at Ages Shown 28-day	56-day	90-day	180-day	1-year
BPN-FA-SP-P	710 (80,000)*	655 (73,750)	--	430 (48,250)	500 (56,500)
BPN-FA-BS-SP-P-1	740 (83,500)	605 (68,500)	--	560 (63,000)	855 (96,650)
BPN-CS-FA-1	575 (65,000)	505 (57,000)	465 (52,500)	435 (49,250)	(Dec 77)
BP-521-25MP	365 (40,750)	355 (39,750)	565** (64,000)	250 (28,000)	(Dec 77)
BPN-FA-BS-SP-P-1 (Type III)	420 (47,500)	325 (36,750)	330 (37,000)	480 (54,250)	(Feb 78)

Note: Specimens were cast vertically in smooth-bore, 6-in.-ID black iron pipe. Specimens 6 in. long were cut from opposite ends of the pipe at test ages shown.

This test is intended to indicate whether there is any loss in bond effectiveness with time. These specimens were cast and cured at ambient laboratory conditions (~70°F) in a smooth-wall, steel pipe and therefore represent the worst condition; any roughness in an actual hole or casing would increase bond strength.

The decrease in bond strengths with time can possibly be explained by normal drying-shrinkage. In actual field placements, where groundwater is continually present, drying-shrinkage could not occur. There is, however, a definite trend toward decreasing values with time in some cases.

* Load (in lb) to break bond is shown in parentheses. Load is an average of two tests.

** This value is probably not representative.

Table 5

Volume Change (3- by 3- by 10-In. Prisms)

	BPN-FA-SP-P		BPN-FA-BS-SP-P-1		BPN-CS-FA-1		BP-521-25MP		BPN-FA-BS-SP-P-1 (Type III)	
Age, days	percent*	percent**	percent*	percent**	percent*	percent**	percent*	percent**	percent*	percent**
2	Initial reading		Initial reading		Initial reading		Initial reading		Initial reading	
3	-0.003		-0.005						0.007	
4	-0.002		-0.003							
5					0.062		0.024			
6					0.074		0.026		0.004	
7	-0.005		-0.002						0.004	
8	-0.007		-0.003		0.084		0.019		0.003	
9	-0.010		-0.006						0.001	
10	-0.011		-0.007						0.000	
11	-0.015		-0.009							
12					0.094		0.004			
13									-0.006	
14	-0.021		-0.014		0.094		-0.001		-0.005	
21	-0.030		-0.024		0.087		-0.012		-0.012	
28	-0.037	Initial reading	-0.033	Initial reading	0.082	Initial reading	-0.022	Initial reading	-0.026	Initial reading
60	-0.063	0.059	-0.066	0.057	0.058	0.022	-0.043	0.002	-0.057	0.003
3 months	-0.092	0.059	-0.104	0.074	0.040	0.027	-0.054	0.002	-0.067	0.015
4 months	-0.113		-0.123		0.026		-0.064		-0.072	
5 months	-0.130		-0.139		0.013		-0.072		-0.088	0.034
6 months	-0.142	0.047	-0.148	0.093	0.007	0.025	-0.074	-0.005	-0.095	0.034
7 months	-0.154		-0.162							
8 months	-0.157		-0.165							
9 months	-0.163		-0.171							
10 months	-0.165	0.045	-0.170	0.092						
11 months	-0.171	0.053	-0.180	0.104						
12 months	-0.178	0.043	-0.187	0.099						

* Specimens in the first column under each mixture were cast and cured at ambient laboratory conditions (~70°F). Even though coated with a protective paint-on skin and stored in double plastic bags, some drying did occur, thereby causing shrinkage.

** Specimens in the second column under each mixture were cured from 1 to 28 days at 120°F to more closely simulate actual downhole conditions. They were not demolded until 28 days age, at which time they were read and inundated in the laboratory-simulated groundwater to be read at ages shown. All inundated specimens showed a general trend toward either continuing expansion or not changing significantly once a peak was reached.

Table 6

Porosity

Mixture	28-Day Ovendry Density g/cc	28-Day Bulk Solid Density g/cc	28-Day Porosity* percent	56-Day Ovendry Density g/cc	56-Day Bulk Solid Density g/cc	56-Day Porosity* percent	180-Day Ovendry Density g/cc	180-Day Bulk Solid Density g/cc	180-Day Porosity* percent	1 Year
BPN-FA-SP-P	1.537	2.540	39.3	1.762	2.643	33.3	1.564	2.463	36.5	
	1.527	2.516	39.1	1.731	2.393	27.7	1.589	2.492	36.2	
BPN-FA-BS-SP-P-1	1.666	2.160	22.0	1.641	2.268	27.6	1.709	2.215	22.84	
	1.655	2.219	25.3	1.660	2.436	31.9	1.710	2.212	22.69	
BPN-CS-FA-1				1.706	2.456	30.5	1.656	2.424	31.7	
				1.699	2.444	30.5	1.663	2.426	31.5	
										Dec 77
BP-521-25 MP				1.438	2.419	40.6	1.410	2.465	42.8	
				1.464	2.391	38.8	1.437	2.458	41.5	
BPN-FA-BS-SP-P-1 (Type III)	1.741	2.083	16.4	1.607	2.259	26.10				Feb 78
	1.751	2.070	15.4	1.672	2.254	25.80		Under way		

Mixture	1 Year** Ovendry Density g/cc	1 Year** Bulk Solid Density g/cc	1 Year** Porosity* Percent
BPN-FA-SP-P			
Not inundated	1.563	2.450	36.2
	1.569	2.569	38.9
Inundated	1.609	2.584	37.7
	1.581	2.667	40.7
BPN-FA-BS-SP-P-1			
Not inundated	1.632	2.382	31.5
	1.636	2.428	32.6
Inundated	1.671	2.317	30.2
	1.662	2.324	28.5

* Porosity measurements were made at 1200-psi pressure (forcing water into the specimen) to determine which specimens exhibited the lowest porosity and if the porosity increased or decreased with time due to varying amounts of pozzolans included in the mixtures. No significant changes are evident at this time.

** Inundated specimens were placed in the simulated groundwater at 28 days age. This was a special one-time test which will be conducted at one year age on all specimens under study.

Table 7

Water Permeability Mixture BPN-FA-BS-SP-P-1 (Type III)

Time Frame days	Permeability, cu ft/sec/sq ft (ft head/ft length) × 10-12, Microdarcies* Shown in ( ) × 10-12			
	No. 1	No. 2	No. 3	No. 4
18-22	45.28	21.27	21.57	5.25
	(0.62)	(0.29)	(0.29)	(0.07)
26.30	38.73	15.27	16.37	5.46
	(0.53)	(0.21)	(0.22)	(0.07)

Note: The mixture described above is the only mixture in which the simulated groundwater permeated the specimen under 200-psi pressure. The other mixtures were impermeable to the simulated groundwater and, in some cases, to tap water also. Note that this mixture does not contain any expansive cement.

In addition, specimens of 3-in. length were also tested for permeability, and none of these specimens exhibited any permeability under the 200-psi water pressure. The 3-in.-long specimens did not include the mixture described above; they were composed of the four mixtures that were not permeable.

* 1 darcey = 7.32×10^{-5} cu ft/sec/sq ft.

Table 8

Comparison of Site Water and Laboratory Water and Comparison of Waters and Precipitates from Various Specimens

Ions	Site Groundwater (Carlsbad, NM)* mg/ℓ	Lab-Simulated Water (Calculated) mg/ℓ	Lab-Simulated Water (Analyzed) mg/ℓ	Lab-Simulated Water in Contact w/Specimen BPN-FA-SP-P mg/ℓ	Lab-Simulated Water in Contact w/Specimen BPN-FA-BS-SP-P-1** mg/ℓ	Precipitate from Top of Specimen BPN-FA-SP-P percent	Precipitate from Top of Specimen BPN-FA-BS-SP-P-1** percent
Cl	206,000	181,700	180,900	177,500	184,200	58.75	56.40
Na	139,825	122,422	--	--	--	38.10	36.57
SO_4	13,350	12,110	12,700	12,400	13,400	2.00	3.50
Mg	675	494	700	11,500	10,400	1.70	0.91
Ca			300	300	600	0.32	0.26
Fe			<100	<100	<100	0.03	<0.01
K						0.08	0.14
pH	6.3		6.3-7.0				

Note: Formula for preparing laboratory simulated groundwater:

NaCl (salt)	50 lb
$MgSO_4 \cdot 7H_2O$	379 g
Na_2SO_4	1090 g
Water	147 lb
(20 gal total volume)	

Water and precipitates in columns 4-7 were collected from permeability specimens.
A chemical analysis of the salt used to prepare the simulated groundwater is as follows:

NaCl, by diff	99.858% (from Carey Salt Co.)
$CaSO_4$	0.105%
$CaCl_2$	0.012%
$MgCl_2$	0.025%
Copper	<1 ppm
Iron	<2 ppm

A chemical analysis of the salt (Morton TFC Purex) used in the two mixtures so indicated in this table had a typical chemical analysis as follows:

NaCl	99.80% (from Morton Salt Co.)
$CaSO_4$	0.17%
$CaCl_2$	0.02%
$MgCl_2$	trace
Sodium ferrocyanide	0.0005%

Some of the Ca shown in columns 6 and 7 could possibly have come from the grout specimen when the precipitate was scraped off. Other Ca could have come from the salt.

* These values are averages of 10 analyses furnished by SC.
** This mixture contains salt (NaCl) in mixing water.

Table 9

Replacement of Cement with Fly Ash and Pozzolans

(by Volume)

Mixture Designation	Fly Ash Replacement by Volume of Total Cement percent	Pozzolan Replacement by Volume of Total Cement percent	Total Fly Ash + Pozzolan percent
BP-519-8	30	8	38
BP-519-12		12	42
BP-519-16		16	46
BP-519-8M		8	38
BP-519-12M		12	42
BP-519-16M		16	46
BP-519-8MP		8	38
BP-519-12MP		12	42
BP-519-16MP		16	46
BP-520-20		20	50
BP-520-30		30	60
BP-520-40		40	70
BP-520-20M		20	50
BP-520-30M		30	60
BP-520-40M		40	70
BP-520-20MP		20	50
BP-520-30MP		30	60
BP-520-40MP		40	70
BP-521-25		25	55
BP-521-35		35	65
BP-521-45		45	75
BP-521-25M		25	55
BP-521-35M		35	65
BP-521-45M		45	75
BP-521-25MP*		25	55
BP-521-35MP		35	65
BP-521-45MP		45	75
BP-522-25		25	55
BP-522-35		35	65
BP-522-45		45	75

(Continued)

* Mixtures selected for further testing.

Table 9 (Concluded)

Mixture Designation	Fly Ash Replacement by Volume of Total Cement percent	Pozzolan Replacement by Volume of Total Cement percent	Total Fly Ash + Pozzolan percent
BP-522-25M	30	25	55
BP-522-35M		35	65
BP-522-45M		45	75
BP-522-25MP		25	55
BP-522-35MP		35	65
BP-522-45MP		45	75
BPN	0	0	0
BPNSP			
BPNSP-R			
BPN-BS			
BPN-BS-SS			
BPN-BS-SS-SP-P			
BPN BS-SS-SP-P-1			
BPN-BS-SS-SP-P-1(A)			
BP-DS			
BP-DS-SP-P			
BP-LS			
BP-LS-SP-P			
BP-LS-SP-P-3			
BPN-FA-BS-SP-P-1*	30		30
BPN-FA-BS-SP-P-2	40		40
BPN-FA-BS-SP-P-3	20		20
BPN-FA-BS-SP-P-4	10		10
BPN-FA-BS-SP-P-1 (Type III)*	30		30
BPN-FA-SP-P*			
BPN-FA-BS-SS-SP-P			
BPN-FA-BS-SS-SP-P-1			
BPN-CS-FA-1*			
BPN-CS-FA-2			

* Mixtures selected for further testing.

Table 10

Representative Brine Solution and Chemical Compounds

Required for Preparation (Furnished by SC)

Representative Brine Solution: Ion	Solution "A" (mg/ℓ) (±3%)	Chemical Compounds for Preparing Brine Solution: Compound	Solution "A" (mg/ℓ)
Na^{+}	42,000	NaCl	100.10 g
K^{+}	30,000	Na_2SO_4	6.20 g
Mg^{++}	35,000	$Na_2B_4O_7 \cdot 10H_2O$	1.95 g
Ca^{++}	600	$NaHCO_3$	960.0
Fe^{+++}	2	NaBr	520.0
Sr^{++}	5	$NaNO_3$	--
Li^{+}	20	KCl	57.20 g
Rb^{+}	20	KI	13.0
Cs^{+}	1	$MgCl_2$	137.00 g
		$MgSO_4$	--
Cl^{-}	190,000	$CaCl_2 \cdot 2H_2O$	2.20 g
SO_4^{--}	3,500	$CaSO_4 \cdot 2H_2O$	--
$B(BO_3^{---})$	1,200	$FeCl_3$	6.0
HCO_3^{-}	700	$SrCl_2 \cdot 2H_2O$	11.0
NO_3^{-}	--	LiCl	125.0
Br-	400	Rb_2SO_4	30.0
I^{-}	10	CsCl	1.3
pH (adjusted)	6.5	pH (adjusted)	6.5
Specific gravity	1.2	Total dissolved solids	306.3 g/ℓ

Note: Brine solutions used in future laboratory work will be of the formulation shown above.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Boa, John A

Borehole plugging program (waste disposal); Report 1: Initial investigations and preliminary data / by John A. Boa, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1978.

16, 19 p. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; C-78-1, Report 1)

Prepared for Department of Energy--Sandia Corp., Albuquerque, N. Mex.

1. Boreholes. 2. Grouts. 3. Radioactive wastes. 4. Stemming. 5. Waste disposal. I. Sandia Corporation, Albuquerque, N. M. Dept. of Energy. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; C-78-1, Report 1.

TA7.W34m no.C-78-1 Report 1